

## How citizens respond to urban pluvial flooding in lowland areas

Comment les citoyens répondent aux problèmes d'inondations pluviales dans les zones urbaines de plaine

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### RÉSUMÉ

Cette étude présente une analyse quantitative des conséquences d'inondations urbaines et les causes associées à la base de données d'un centre d'appel municipal. L'utilisation de ce type de données dans l'analyse des risques d'inondation, en particulier dans les zones de plaine, offre l'avantage de couvrir les grandes et les petites inondations, ces dernières constituant une partie importante du risque d'inondation. Les résultats de cette étude montrent que les inondations urbaines posent des risques plus élevés pour le trafic que pour les dommages aux propriétés privées. Les inondations posent de faibles risques pour la santé publique. De plus amples détails sur les causes associées à différents types de conséquences montrent que les embâcles des bouches d'égout (avaloirs) sont la cause principale de tous les types d'inondations. Cela implique que les conséquences des inondations en milieu urbain peuvent être effectivement réduites en limitant le nombre d'embâcles. La surcharge des égouts à la suite de fortes pluies est moins importante comme cause d'inondation que les embâcles, ce qui indique que la capacité insuffisante des égouts n'est pas une cause de préoccupation majeure pour le cas présenté.

### MOTS CLÉS

Risques d'inondation, assainissement urbain, données de centres d'appel municipaux

### ABSTRACT

In this paper data from municipal call data are used in a quantitative analysis of urban flooding consequences and associated causes. The advantage of the use of this type of data for flood risk analysis, particularly in lowland areas is that they capture both large and small flood incidents, the latter constituting a major part of flood risk in these areas. The results show that urban flood risk related to traffic disturbance is high compared to damage to private properties. Total flood risk related to human health is small. Further details on the causes associated with different types of consequences show that gully pot blockages are the main cause of all types of flooding consequences. This implies that consequences of urban flooding can best be reduced by reducing the number of blocked gully pots. Sewer overloading as a result of heavy rainfall is mentioned in a far smaller number of calls, indicating that insufficient sewer capacity is not a major cause of concern.

### KEYWORDS

Flood risk; urban drainage; citizens' call data

## 1 INTRODUCTION

Urban drainage systems in lowland areas are typically designed to cope with rainfall events with return periods of 2 to 5 years (e.g. RIONED, 2004). As a result, urban flood incidents occur at a regular basis. Many of these incidents are characterised by small flood depths and small geographical extension. Stage-damage functions are not applicable to quantify damage for such small flood depths (Merz et al., 2005; Apel et al., 2004; Dutta et al., 2003), because they are generally developed for flood depths between 0 and 5 meters (e.g. Apel, in press, Chang 2008 and Dutta, 2003) and uncertainty increases for applications to smaller flood depths. Additionally, for many urban flood incidents, direct damage forms a small if not negligible portion of flood consequences, where intangible damage in the form of disruption of road traffic and inconvenience for pedestrians caused by pools in front of shops, on parking lots and sidewalks is more important. Indirect and intangible damages are more difficult to quantify than direct damage. For convenience, indirect damage is sometimes quantified as a fixed percentage of direct damage (FHRC, 2003), if indirect damage is expected to be small compared to total damage.

Urban drainage systems are designed to function in accordance with prescribed flooding standards, mostly defined in terms of maximum flooding frequencies. Standards are set by local or regional authorities; some differentiate between occupational land uses, like residential and commercial areas. By doing so, protection standards implicitly seek to establish a trade-off between investment costs for flood protection and expected damage from flooding: for higher expected damage, stricter flooding standards apply. This trade-off is based on a qualitative assessment of expected flood damage; a lack of quantitative historical data on flooding incidents prevents quantitative assessment of urban pluvial flooding frequencies and damage. Application of cost-benefit analysis requires time-series of flood event occurrences and associated damage. These can be obtained in two ways: by simulating urban flood events and damage with a combination of hydrodynamic models and modelled relationships between flood characteristics and damage or by direct measurement of the occurrences and damage associated with real flood events.

In this paper we present historical data on flood events over a period of ten years and use these in a quantitative flood risk analysis. The data relate to a flat urban area, where flooding frequencies are high compared to hilly areas and where associated flood damage is relatively small. Flood risk analysis for such events poses a special difficulty: damage is largely intangible as it consists of disruption of road traffic and inconvenience for pedestrians caused by pools in front of shops, on parking lots and sidewalks. Quantification of this type of damage in monetary terms, as is usually done for damage to buildings e.g. in river flooding analysis, is difficult. This paper presents an alternative approach which entails assessment of the various impacts of flooding on citizens by using data from municipal call centres. Municipal call data contain detailed information on causes and consequences of urban flood incidents. These data are used to quantify urban pluvial flood risk; the approach is demonstrated by application to a case study.

## DATA AND METHOD

Municipal call centres register call information on urban drainage problems observed by citizens. Calls related to urban drainage cover a variety of details on problem causes and consequences that traditional monitoring or modelling finds it difficult to address, such as details on in-house flooding and maintenance-related problems like pipe blockages.

Ten years of call data on small and large flood events in Haarlem (the Netherlands), a city of about 150000 inhabitants, are used in a flood risk analysis. Table 1 provides a summary of data for the Haarlem case.

<b>Data case study</b>	<b>Haarlem</b>
Number of inhabitants	147000
Length of sewer system (% combined)	460 km (98%)
Total surface connected to sewer system	1110 ha
Total number of gully pots	42500
Maximum ground level variation	20 m
<b>Rain gauges</b>	
Period of rainfall data	12-06-1997 to 02-11-2007
<b>Call register</b>	
Period of call data	12-06-1997 to 02-11-2007
Total number of calls on urban drainage	6444
Length of data series	3788 days
<b>Maintenance regime</b>	
Gully pot cleaning	1x/year + upon calls
Sewer cleaning	62km/yr (13% of total sewer length)

Table 1. Summary of data for the city of Haarlem: sewer system characteristics, call data in municipal call register, rainfall data

Calls on urban drainage events are selected from the call centre database which results in a dataset of 6444 calls. Call data consist of a unique call number, date of the call, street name where a problem has occurred and a telegram style text that describes what the caller has said. In most cases a second text is added that describes the results of on-site checking and actions undertaken to solve the call. Calls are assigned to independent rain events; Independent rain events are defined by a separation of 24 or more hours of dry weather.

To prepare the data for risk analysis, call data are classified according to the causes and consequences of the flood incidents they describe and are assigned to independent rain events. Cause classes have been used in a quantitative fault tree analysis; for results of this analysis we refer to ten Veldhuis et al. (2009). Consequence classes are defined based on common damage characteristics found in the call texts, as detailed as the information in the call texts allows. They incorporate direct, tangible and intangible damages of different severities. For instance, flooding of road tunnels and main traffic arteries has more severe consequences than flooding of residential roads or cycle paths. An example of consequence classes is given in table 2.

<b>Consequence classes</b>	
1) Flooding in commercial building	4) Flooding of residential road
2) Flooding in residential building	5) Flooding at bus stop bust station/taxi stand
3) Flooding in road tunnel	6) Flooding with wastewater (toilet paper/bad smell)

Table 2. Example of consequence classes for urban flood risk analysis

The result of call classification based on independent events is a matrix of independent events in rows and consequence classes in columns. Table 3 gives an example of the classification results matrix. The classification results are used to quantify flood risk, where risk is defined as the product of probability and flood consequences; consequences are expressed in terms of number of calls per consequence class.

Independent events $S_1$ to $S_n$ ; 518 for the Haarlem case	Consequence classes				
	Number of calls per event, per consequence classes; range 0 to 27 calls per event per consequence class, for the Haarlem case.				
	Flooding in commercial building	Flooding in residential building	Flooding in road tunnel	Flooding of residential road	Etc.
$S_1$	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$	$X_{1,4}$	$X_{1,n}$
$S_2$	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$	$X_{2,4}$	$X_{2,n}$
$S_i$	$X_{i,1}$	$X_{i,2}$	$X_{i,3}$	$X_{i,4}$	$X_{i,n}$
$S_n$	$X_{n,1}$	$X_{n,2}$	$X_{n,3}$	$X_{n,4}$	$X_{n,n}$

Table 3. Consequence class severities and probabilities as input for risk curves per individual consequence class

The number of calls is assumed to provide a measure for the number of locations where flood consequences occurred. In this paper call classification results are used as a quantitative measure for intangible flood damage, based on the assumption that the amount of calls per incident is indicative of the number of affected citizens. This is confirmed by the correlation between rainfall volume and numbers of flood-related calls per rainfall event: a correlation coefficient of 0.76. This indicates that call numbers increase with increasing rainfall volumes which are likely to induce more flooding (figure 1). Moreover, calls reveal the acceptability of flooding consequences to citizens: citizens make a call because they experience some kind of inconvenience or damage that they want to see removed.

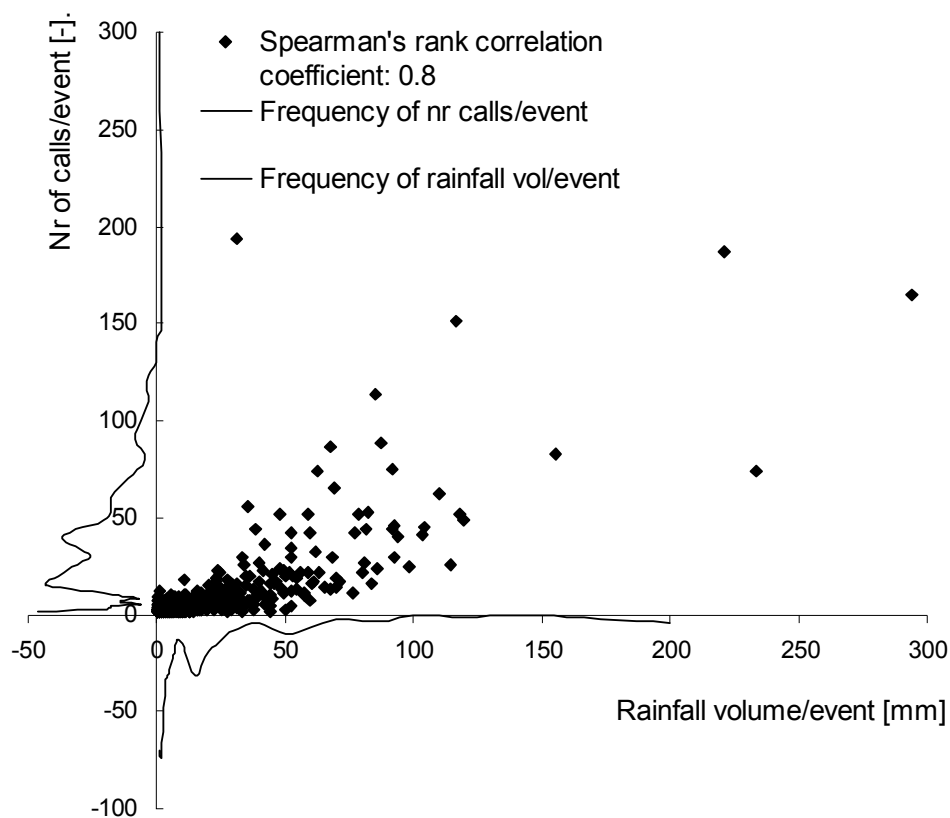


Figure 1. Correlation between the number of calls per event and rainfall volume per event. Frequencies the number of data for number of calls per event and rainfall volumes are displayed as well.

Flood risk is quantified for each individual consequence class. The results provide insight into the risk

associated with different types of consequences, e.g. the risk of road flooding can be compared to the risk of flooding of commercial buildings. This information can be used to set priorities for flood risk reduction: if a consequence class presents high flood risk, this may be a reason to take measure to reduce flood risk associated with that particular consequence class. Alternatively, if the consequence class concerned is not a priority in flood risk management, e.g. flooding of green areas, the results would confirm the outcome of priority-setting.

## 2 RESULTS

The results of the call classification are summarised in table 4. Out of 6444 classified calls, 1793 calls (27%) mention consequences related to flooding. In 3646 (57%) of the calls no consequence is mentioned; 1005 (16%) of the calls refer to consequences other than flooding. Flooding on streets is noted most often as a consequence. This can be explained by the more general definition of this class as opposed to e.g. flooding in front of entrance to building. Therefore this class contains both calls of real street-flooding and calls that due to a lack of detail in the call text could not be assigned to more specific classes. This is a drawback of different levels of detail in class definition that can only be avoided by generalising classes which in its turn leads to a loss of information from detailed call texts.

Table 4 shows that detailed classification results in a number of sparse consequence classes. In second instance, classes are lumped to a higher aggregation level in order to obtain a more balanced classification dataset. The classification results at the higher aggregation level are shown in table 4, as totals in bold numbers.

Aggregated consequence class	Consequence classes	Nr. of calls in class	
		(nr)	(%)
Consequences for human health: physical harm/ infection	Flooding with wastewater (toilet paper/ excreta)	61	3.4
	Manhole lid removed	7	0.4
<b>Total human health</b>		<b>68</b>	<b>3.8</b>
Consequences for buildings and infrastructure: damage to private properties	Flooding in residential building	116	6.5
	Flooding in commercial building	34	1.9
	Flooding in basement/crawl space	173	9.6
	Water splashes onto building	26	1.5
	Flooding of gardens/park	74	4.1
<b>Total private properties</b>		<b>423</b>	<b>23.6</b>
Consequences for traffic: cars, cyclists, pedestrians	Flooding in tunnel	13	0.7
	Flooding at bus stop/bus station/taxi stand	18	1.0
	Flooding in shopping street/commercial centre	117	6.5
	Flooding in front of entrance to shop/bar/hospital	55	3.1
	Flooding in front of entrance to residential building	65	3.6
	Flooding on residential/main street	655	36.5
	Flooding on cycle path	133	7.4
	Flooding on sidewalk/footpath	73	4.1
	Flooding on parking space	173	9.7
<b>Total traffic</b>		<b>1302</b>	<b>72.6</b>
<b>Total number of calls relevant for flooding</b>		<b>1793</b>	<b>100%</b>
No consequence mentioned		3646	
Consequence other than flooding		1005	
<b>Total of calls</b>		<b>6444</b>	

Table 4. Call classification results for aggregated and for detailed flood consequence classes

Figure 2 shows 3 risk curves based on aggregated flood consequence classes: human health, private properties and traffic. The horizontal axis shows the number of calls per consequence class per event with a maximum of 27. The vertical axis shows the cumulative probability of at least a given number of calls. For example, the probability of at least 1 call is 0.05 for health consequences, 0.28 for damage to private properties and 0.9 for disturbance to traffic. The curve shows that traffic disturbance is far more likely to be mentioned by callers than damage to private properties and human health consequences. Human health consequences are mentioned in maximum 3 calls per incident; damage to private properties generates a maximum of 12 calls per incident.

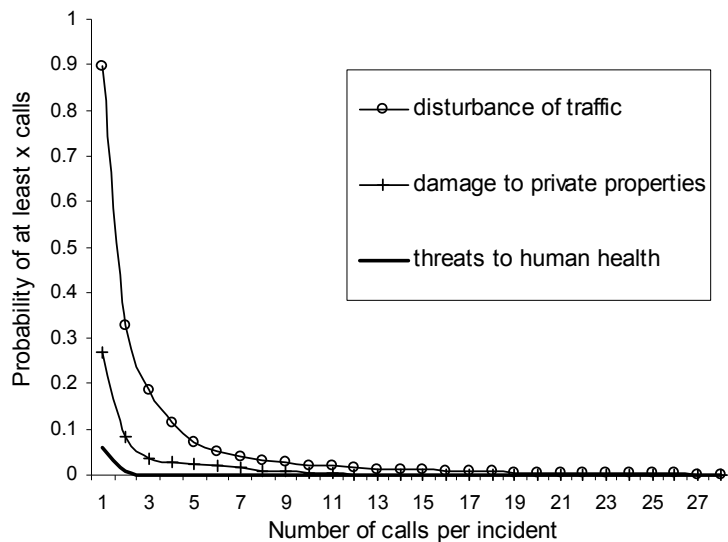


Figure 2. Risk curves for aggregated urban flood consequence classes

Risk curves for aggregated consequences are useful to quickly distinguish between higher and lower risks. In figure 2, the risk curve for 'disturbance of traffic' lies furthest towards the upper right corner of the graph, so the total associated risk is highest for this curve. Total risk for damage to private properties is lower than for disturbance of traffic and higher the risk of threats to human health. The curves also show that all risks are mainly related to low-severity incidents in the sense that the probability of a high number of calls is low, while the probability of 1 or 2 calls per incidents is much higher. It is up to decision makers to decide whether total risk should be reduced by further reducing the probability of high-call-numbers-events or by reducing the probability of low-call-numbers events.

Table 5 provides further information as to how probabilities could be reduced: it shows how the number of calls per aggregated consequence class is related to five causes of urban flooding. The main cause of urban flooding, for the case of Haarlem, is gully pot blockage, for all three types of consequences. The table shows that even for damage to private properties, sewer overloading, as a result of heavy rainfall is but the third most important cause of flooding. This implies that all consequences of urban flooding can best be reduced by reducing the number of blocked gully pots.

Aggregated consequence classes	Threats to human health	Damage to private properties	Traffic disturbance
Cause classes			
Blocked or full gully pot	5	117	791
Gully pot manifold blocked or broken	2	8	76
Water pooling on the surface, no outflow	0	17	55
Sewer overloading	0	8	58
Sewer pipe blocked	3	0	3
<b>Total</b>	<b>10</b>	<b>150</b>	<b>983</b>

Table 5 Call classification results for aggregated consequence classes and for 5 causes of flooding.

## 2.1 Uncertainty aspects

Flood risk estimations are subject to large uncertainties, whether based on historical data, theoretical modelling or a combination of both (see e.g. Apel et al., 2004 and Merz et al., 2004). Call data are a valuable source of historical data on flood incidents that has been little researched so far. A source of uncertainty particular for flood risk estimations based on these data is that call data report only a portion of the actual flood incidents. It is unknown whether reported incidents are representative nor what proportion they form of the total amount of incidents. Also, call information can be subjective and comes from non-experts whose information can be incorrect. This source of uncertainty is greatly reduced when calls are checked on-site by technical experts or when calls are handled by trained people using good protocols.

On the other hand, call data directly convey citizens' experiences regarding adverse effects of wastewater and flooding, which urban drainage systems are designed to protect citizens from. Therefore call data are a useful source of information to prioritise actions for flood risk reduction.

## 3 CONCLUSIONS

In this paper call data on urban flood incidents are used in a quantitative risk analysis. Call data per incident are used as a measure for incident severity. The advantage of the use of this type of data for flood risk analysis, particularly in lowland areas is that they capture both large and small flood incidents, the latter constituting a major part of flood risk in these areas.

Risk curves that depict flood risk for a range of flood incidents, from high-probability low-consequence incidents to low-probability high consequence ones are used to illustrate the results of quantitative risk analysis based on call data. Risk curves for aggregated consequence classes show that urban flood risk related to traffic disturbance is high compared to damage to private properties. Total flood risk related to human health is small.

Further details on the causes associated with different types of consequences shows that gully pot blockages are the main cause of all types of flooding consequences. This implies that all consequences of urban flooding can best be reduced by reducing the number of blocked gully pots. Sewer overloading as a result of heavy rainfall is mentioned in a far smaller number of calls, indicating that insufficient sewer capacity is not a major cause of concern for the case of Haarlem.

Since call data directly convey citizens' experiences in urban flood incidents, they give valuable information about the degree of protection that urban drainage systems provide against adverse affects of wastewater and flooding. Flood risk analysis based on hydraulic modelling and stage-damage functions do not provide this type of information and mostly focus on severe, low probability flood incidents. Call data complement these analyses in a valuable way. In addition, call data provide information about consequences as well as associated causes of flooding. Thus, they provide valuable input as to a how flooding consequences can be effectively reduced.

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